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System Maturity and Architecture Assessment Methods, Processes, and Tools

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14. ABSTRACT
At present, the System Readiness Level (SRL), as developed by the Systems Development & Maturity Laboratory (SysDML) at Stevens Institute of Technology, is a descriptive model that characterizes the effects of technology and integration maturity on a system engineering effort a systems development program. One of the current deficiencies in system maturity assessments (measure of readiness) is that it is performed independent of any systems engineering tools or supporting artifacts, which could reduce the level of subjectivity in an assessment and reliability in the results. The advent of system engineering modeling tools has enabled system architects to better understand a system by depicting various views of the system and its components. For this purpose, architectural frameworks have been introduced for various domains and industries to support a common language and set of tools for developing a system. The research objectives of this task are œIdentify the systems engineering architectural artifacts that support the assessment of a technology maturity (via TRLs), integration maturity (via IRLs), and likewise system maturity (via SRLs). œCorrelate SE architectural artifacts to supported views and artifacts within the DoDAF that enable TRL and IRL assessment. œDevelop a maturity assessment tool that works with standard industry SE architecture tools.

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ABSTRACT

At present, the System Readiness Level (SRL), as developed by the Systems Development & Maturity Laboratory (SysDML) at Stevens Institute of Technology, is a descriptive model that characterizes the effects of technology and integration maturity on a system engineering effort a systems development program. One of the current deficiencies in system maturity assessments (measure of readiness) is that it is performed independent of any systems engineering tools or supporting artifacts, which could reduce the level of subjectivity in an assessment and reliability in the results. The advent of system engineering modeling tools has enabled system architects to better understand a system by depicting various views of the system and its components. For this purpose, architectural frameworks have been introduced for various domains and industries to support a common language and set of tools for developing a system. One of the widely adopted frameworks in the defense sector of the United States is the Department of Defense Architecture Framework (DoDAF). In addition, Department of Defense (DoD) subcontractors have adopted DoDAF as part of their systems engineering process, and industry consortia are currently working on adopting the DoDAF vocabulary and products to complement their standardized approaches to systems and software development. With the current challenges in systems maturity assessment and the advancement of systems engineering architecture tools, this research has attempted to:

- Identify the systems engineering architectural artifacts that support the assessment of a technology maturity (via Technology Readiness Levels), integration maturity (via Integration Readiness Levels), and likewise system maturity (via System Readiness Levels);
- Correlate systems engineering architectural artifacts to supported views and artifacts within the DoDAF that enable TRL and IRL assessment; and
- Develop a maturity assessment tool that works with standard industry SE architecture tools (e.g. Sparx Enterprise Architect, IBM Rhapsody).

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1 SUMMARY

At present, the System Readiness Level (SRL), as developed by the Systems Development & Maturity Laboratory (SysDML) at Stevens Institute of Technology[1], is a descriptive method that characterizes the effects of technology and integration maturity on the system engineering effort of a Department of Defense (DoD) program. The SRL and supporting assessment methodology has proven itself to be a promising mechanism for understanding the effects of technology and integration maturity in a systems engineering context. In addition, the current tools and methods have demonstrated utility for defining system status and providing leading indicators of integration risk. While the SRL method has been subjected to a series of validations with DoD programs and organizations (e.g. US Army ARDEC, NAVSEA PMS 420, Lockheed Martin, Northrop Grumman), it still has not reduced the level of subjectivity in the assessment and reliability in the results. The success of the SRL's implementation thus far highlights the potential benefits of extending the research to explore the application of the SRL to broader areas of the systems engineering and management domains, particularly with respect to systems of systems implementations, where validated models and supporting tools are lacking.

One of the current deficiencies in system maturity assessments is that it is performed independent of any systems engineering tools or supporting artifacts, which could reduce the level of subjectivity in an assessment and reliability in the results. Within the methods, processes, and tools of systems engineering architecting, there exists a substantial base of architectural artifacts that have the potential to significantly reduce the subjectivity and in essence increase the reliability in a system maturity assessment.

The advent of system engineering modeling tools has enabled system architects to better understand a system by depicting various views of the system and its components. For this purpose, architectural frameworks have been introduced for various domains and industries to support a common language and set of tools for developing a system. Architectural frameworks support the need for a more structured approach to manage complexity whilst balancing all appropriate user perspectives. One of the widely adopted frameworks in the defense sector of the United States is the Department of Defense Architecture Framework (DoDAF). In addition, DoD subcontractors have adopted DoDAF as part of their Systems Engineering process, and industry consortia are currently working on adopting the DoDAF vocabulary and products to complement their standardized approaches to systems and software development. Although there are 26

[1] For a detailed description of the SRL methodology see Sauser, B., J.E. Ramirez-Marquez, D. Nowicki, A. Deshmukh, and M. Sarfaraz. Development of Systems Engineering Maturity Models and Management Tools. Systems Engineering Research Center Final Technical Report 2011-TR-014, January 2011

views to document the entire architecture, there are a handful of views that can be used for the purpose of system maturity assessment.

Thus with the current challenges in systems maturity assessment and the advancement of systems engineering architecture tools, this research seeks to:

[1] Identify the systems engineering architectural artifacts that support the assessment of a technology maturity (via Technology Readiness Levels), integration maturity (via Integration Readiness Levels), and likewise system maturity (via System Readiness Levels);
[2] Correlate systems engineering architectural artifacts to supported views and artifacts within the DoDAF that enable TRL and IRL assessment; and
[3] Develop a maturity assessment tool that works with standard industry SE architecture tools (e.g. Sparx Enterprise Architect).

2 INTRODUCTION

Defense programs are often balancing against schedule slippages, cancellations, and failure to meet performance objectives. In addition, numerous reports have described the challenges of maturity as it relates to integrating technology solutions into systems. To that end, the Technology Readiness Level (TRL) has been used within the Department of Defense (DoD) as a metric in assessing the risks associated with a developing or acquired technology for a system solution. However, one of the deficiencies in using the TRL metric is that estimates of maturity can be reliant on subjective assessments (Mahafza 2005; Azizian 2009; Sauser and Ramirez-Marquez 2009; Magnaye, Sauser et al. 2010). Although there are guidelines and tools to support the assessment process (Nolte, Kennedy et al. 2003; DoD 2009), the final estimation of maturity is left to the evaluator(s) (Tan, Sauser et al. 2011).

It is the goal of this research to lay the foundations for the formulation of a more informed decision support framework and supporting tools that will assist practitioners and managers in measuring and determining the maturity of technology and their requisite integrations. To accomplish this, maturity artifacts, the information needed by decision makers to make informed decisions, are identified from standardized sources of information and mapped to system architectural information to assist in maturity assessment.

Architectures facilitate decision making by conveying the necessary information to the decision maker by presenting architecture information, and the TRL and IRL provide a metric to assess the maturity of a technology and their integrations at any given time. Architecture data supports acquisition program management and systems development by representing system concepts, design, and implementation as they mature over time, which enable and support operational requirements (DoDAF 2007). Therefore, this research explores the combined use of the Department of Defense Architecture Framework (DoDAF) with TRL and the Integration Maturity Level (IRL) metrics for maturity assessment.

The development of this research is intended to lead to a more informative and less subjective method for the assessment of system maturity. In effect, this research would hope to provide a contextual decision making framework for effectively using the TRL and IRL metrics to reduce the risk associated with investing in immature technologies (GAO 2005). The significance of this research lies in presenting a framework for determining component maturity, which can be used by decision makers to evaluate the maturity of a system. The information presented in the framework is not intended to be used as a “check the box” event, instead, it is supposed to serve as a platform to select models that can be used to harvest information for making more informed decisions on technology and integration maturity. It is expected that the development of an assessment platform based on a set of rules, guidelines and ontology for consistency, repeatability, and traceability will allow for a more objective approach to maturity assessment. We reiterate, this research seeks to:

[1] Identify the systems engineering architectural artifacts that support the assessment of a technology maturity (via Technology Readiness Levels), integration maturity (via Integration Readiness Levels), and likewise system maturity (via System Readiness Levels);
[2] Correlate systems engineering architectural artifacts to supported views and artifacts within the DoDAF that enable TRL and IRL assessment; and
[3] Develop a maturity assessment tool that works with standard industry SE architecture tools (e.g. Sparx Enterprise Architect).

3 BACKGROUND

3.1 METRICS

Metrics act are indicators to measure the attribute of an object of interest in order to make more informed decisions (Jacoby and Luqi 2007). The use of metrics in the realms of project management and system development and operational sustainment are a proven and successful practice (Gove, Sauser et al. 2007). Dowling and Pardoe (2005) lists four rules required to create a successful metric:

1) The way the value is used should be clear;
2) The data to be collected for the metric sould be easily understood and easy to collect;
3) The way of deriving the value from the data should be clean and as simple as possible; and
4) Those for whom the use of the metric implies additional cost should see as much direct benefit as possible.

Based on these rules we can then define metrics into two classifications: Descriptive or Prescriptive (Fan and Yih 1994; Tervonen and Iisakka 1996; Harjumaa, Tervonen et al. 2008). Descriptive metrics, or sometimes referred to as hard metrics, can be objectively measured, are quantifiable, and have minimal variability when used between observers. For example, the height of an individual, proportion of telephone calls answered, or machine downtime. On the other hand, prescriptive metrics, or soft measures, are those which are qualitative, judgmental, subjective, and based on perceptual data. For example, customers' satisfaction with speed of service or managers' assessment of staff attitude towards customers (Dowling and Pardoe 2005). With prescriptive metric, when not used in the proper context, multiple observers can assess the same problem and yield significantly different results.

Within systems engineering we have come to rely on prescriptive metrics for making managerial and at times engineering decisions because there is limited descriptive data. Prescriptive metrics are strongly based on human interpretation that can be influenced by personal biases and preferences. Lee and Shin (Lee and Shin 2000) found that egocentric biases and personal goals play a large role in human beings' evaluation process. Since such cognitive bias is involved in assessment, subjectivity is more or less inherent in our estimation and it is very hard to avoid its influence (Yan, Xu et al. 2006).

Prescriptive metrics are vital in providing fuller insight that some descriptive metrics cannot, yet perspective metrics have been wrongfully considered as less important. While descriptive metrics take into account more qualitative factors, it is possible to bridge and attempt to quantify qualities that are difficult to assess with both collectively. This research makes strides to moving the prescriptive metrics of TRL and IRL closer to a descriptive state. But, with any prescriptive metric, for effective use, there is a need to understand their boundaries and limitations.

3.2 Readiness Levels

The success behind using TRL has opened up the path for researchers to identify alternative readiness (maturity) levels that will complement TRL. TRL has been implemented and modified since the early 1990's in government programs and has proved to be a beneficial metric in assessing the risks associated with a developing or acquired technology (see Table 1 for the definitions and description of TRL levels). Just as the ways that agencies or organizations have adopted the TRL metric or created new readiness levels have been diverse, so have the ways that they employ these metrics (Tan, Sauser et al. 2011). Graettinger, et al. (Graettinger, Garcia et al. 2002) reports that approaches for readiness level implementation among agencies are quite broad, which range from a formal software tool to more informal face-to-face discussions between stakeholders.

Table 1 Technology Readiness Level

TRL	Definition	Description
1	Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard validation in a laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
5	Component and/or breadboard validation in a laboratory environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environ- ment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7	System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an air- craft, in a vehicle, or in space).
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to deter- mine if it meets design specifications.
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.

After the DoD began its adoption of the TRL metric, much effort was invested in applying the metric to technologies in ongoing programs and projects. To support this, a Technology Readiness Assessment (TRA) Deskbook has provided the guidance for performing technology maturity assessments prior to incorporating these technologies into systems in defense programs. In addition, TRL calculators have been created (Nolte, Kennedy et al. 2003) as a tool in technology maturity assessment. For each of these efforts, guidance such as readiness level descriptions and/or checklists have been used individually or in combination.

However, critics of the TRL system have argued that the TRL metric combines many dimensions of technology readiness into one metric (Smith 2004). Kaplan and Norton have said," what you measure is what you get (Kaplan and Norton 2010), hence the failure to consider an attribute can lead to inaccurate assessment.

Given the emerging needs for a measure of system readiness, in 2006 the SysDML at Stevens Institute of Technology presented the concept of a System Readiness Level for managing system development (Sauser, Verma et al. 2006). As a result, in 2007 the SysDML in collaboration with the US Navy PMS 420/SPAWAR and Northrop Grumman Corporation were chartered to define a system maturity scale and supporting methodology. The core requirements included that the scale must be robust, repeatable, and agile so outputs could not only be trusted and replicated, but that the methodology as a whole be easily transferred to a variety of different applications and architectures. In response to this challenge, the concept of a System Readiness Level (SRL) that would incorporate a TRL and an Integration Readiness Level (IRL) was developed as depicted in Figure 1 (Sauser, Verma et al. 2006)

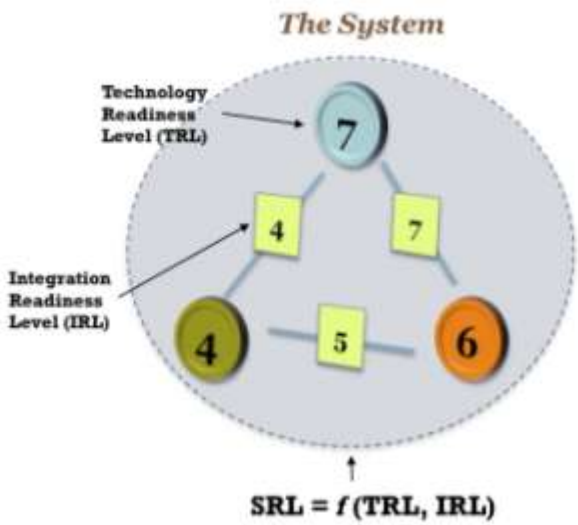

Figure 1 System Readiness Level

Similar to TRL, the IRL is defined as a series of levels that articulate the key maturation milestones for integration activities (see Table 2 for the definitions and description of IRL levels). The introduction of an IRL to the assessment process not only provides a check as to where a technology is on an integration readiness scale but also presents a direction for improving integration with other technologies. Just as a TRL is used to assess the risk associated with developing technologies, the IRL is designed to assess the risk associated with integrating these technologies. For more details on the formulation of the IRL see (Sauser, Gove et al. 2010).

Table 2: Integration Readiness Level

IRL	Definition	Description
9	Integration is Mission Proven through successful mission operations.	IRL 9 represents the integrated technologies being used in the system environment successfully. In order for a technology to move to TRL 9 it must first be integrated into the system, and then proven in the relevant environment, so attempting to move to IRL 9 also implies maturing the component technology to TRL 9.
8	Actual integration completed and Mission Qualified through test and demonstration, in the system environment.	IRL 8 represents not only the integration meeting requirements, but also a system-level demonstration in the relevant environment. This will reveal any unknown bugs/defect that could not be discovered until the interaction of the two integrating technologies was observed in the system environment.
7	The integration of technologies has been Verified and Validated and an acquisition/insertion decision can be made.	IRL 7 represents a significant step beyond IRL 6; the integration has to work from a technical perspective, but also from a requirements perspective. IRL 7 represents the integration meeting requirements such as performance, throughput, and reliability.
6	The integrating technologies can Accept, Translate, and Structure Information for its intended application.	IRL 6 is the highest technical level to be achieved, it includes the ability to not only control integration, but specify what information to exchange, unit labels to specify what the information is, and the ability to translate from a foreign data structure to a local one.
5	There is sufficient Control between technologies necessary to establish, manage, and terminate the integration.	IRL 5 simply denotes the ability of one or more of the integrating technologies to control the integration itself; this includes establishing, maintaining, and terminating.
4	There is sufficient detail in the Quality and Assurance of the integration between technologies.	Many technology integration failures never progress past IRL 3, due to the assumption that if two technologies can exchange information successfully, then they are fully integrated. IRL 4 goes beyond simple data exchange and requires that the data sent is the data received and there exists a mechanism for checking it.
3	There is Compatibility (i.e. common language) between technologies to orderly and efficiently integrate and interact.	IRL 3 represents the minimum required level to provide successful integration. This means that the two technologies are able to not only influence each other, but also communicate interpretable data. IRL 3 represents the first tangible step in the maturity process.
2	There is some level of specificity to characterize the Interaction (i.e. ability to influence) between technologies through their interface.	Once a medium has been defined, a “signaling” method must be selected such that two integrating technologies are able to influence each other over that medium. Since IRL 2 represents the ability of two technologies to influence each other over a given medium, this represents integration proof-of-concept.
1	An Interface between technologies has been identified with sufficient detail to allow characterization of the relationship.	This is the lowest level of integration readiness and describes the selection of a medium for integration.

With the ability to assess both the technologies and integration elements along a numerical maturation scale, the next challenge was to develop a metric that could assess the maturity of the entire system under development. Therefore, the SRL was developed that could incorporate both TRLs and IRLs system maturity assessment (Sauser, Ramirez-Marquez et al. 2008). The rationale behind the SRL is that in the development lifecycle, one would be interested in addressing the following considerations:

- Quantifying how a specific technology is being integrated with every other technology to develop the system.
- Providing a system-wide measurement of readiness.

For a detailed description of the SRL methodology see Sauser, B., J.E. Ramirez-Marquez, D. Nowicki, A. Deshmukh, and M. Sarfaraz. Development of Systems Engineering Maturity Models and Management Tools. Systems Engineering Research Center Final Technical Report 2011-TR-014, January 2011 or visit http://www.SysDML.com

3.3 SYSTEM ARCHITECTURE AND DODAF

The International Council on Systems Engineering (INCOSE) defines system architecture as "the arrangement of elements and subsystems and the allocation of functions to them to meet system requirements" (INCOSE 2007). System architectures can help systems engineers to examine a system from various perspectives, and for that, architectures help decision makers to reason about a problem (Dimov, Stankov et al. 2009). In support of this, modeling is used to improve communication and to involve stakeholders, developers, integrators, vendors, and testers in the process (Friendenthal 2008).

A National Research Council (2008) study recently highlighted that architecture can mitigate internal and external system complexity risk by partitioning the system into separately definable procurable parts and recommending a rigorous development of systems architecture early on in the program. Much of this information is efficiently and effectively conveyed and managed via architecture products (Hughes 2010). In the mid 1990s, the DoD determined that a common approach was needed for describing its architectures, so DoD systems could efficiently communicate and interoperate during joint and multinational operations (Sibbald 2004). This need led to the introduction of the Command, Control, Communication, Computers, and Intelligence, Surveillance and Reconnaissance (C4ISR) architectural framework. Subsequently, further revisions of C4ISR led to version 1.0 of DoDAF released in 2003. Ultimately, DoD directives resulted in the official use of DoDAF 1.0. The next version, DoDAF 1.5, was published in 2007 and incorporated net-centric concepts (DoDAF 2007). Version 2.0 (DM2) was released in 2009, placing the focus on architectural data rather than developing products (DoDAF 2009). DoDAF continues to evolve, but for the purposes of this research we focused on DoDAF 2.0.

There are a number of notable changes from previous version of DoDAF (1.0/1.5) to DM2. For example:

- DM2 does not require all DoDAF-described models to be created. Key process owners have the responsibly to decide which activity model is created, but once that is selected, a necessary set of data for that activity model is required (Department of Defense 2009).

- Another feature introduced in DM2 was Fit-for-Purpose (FFP) models. FFP models are useful in decision making, and enable the architect to focus on collecting and creating views that are necessary for the decision maker's requirements, and focusing the architecture to align to the decision-maker's needs

- The DoDAF 2.0 describes the technical aspects of data collection and presentation, organizer thought the DM2, enabling the requirements of architecture stakeholders and their viewpoints to be realized through both federation efforts, and data sharing. The DM2 defines architectural data elements and enables the integration and federation of Architectural Descriptions"(DoD Architecture Framework). The DM2 provides information needed to collect, organize, and store data in a way easily understood. The presentation description of various types of views in Volumes 1 and 2 provide the guidance for developing graphical representations of that data that is useful in defining acquisition requirements under the DoD Instruction 5000-series.

Aside from DoDAF 2.0's new features that can help in acquisition processes and technology management, researchers have studied using DoDAF in technology management. Dimov, Stankov, et al. (2009) presented an architecture-oriented modeling approach to assist in acquisition systems for one of Bulgaria's force-management's subsystems. Hughes (2010) from the Air Force Institute of Technology used a concept maturity model to help to uncover the unknowns that plague a system development. Hughes suggested using maturity elements to assess and mature a concept at a given decision point. The limitation in this research is that an explanation in the level of detail is required for each maturity element. Scharch and Homan (2011) latter examined the applicability and validity of Hughes framework through a three tiered methodology, and also took an improvement approach to the framework. Philips (2010) introduced Human Readiness Level to complement TRL in program risk management structures, and synthesized the technical details of the Human View in relation to DoDAF. Although there are many systems architecture platforms that can support maturity assessment, this research utilizes the features of the DoDAF 2.0 models.

4 Research Results

As stated, this research had three objectives:

[1] Identify the systems engineering architectural artifacts that support the assessment of a technology maturity (via Technology Readiness Levels),

integration maturity (via Integration Readiness Levels), and likewise system maturity (via System Readiness Levels);

[2] Correlate systems engineering architectural artifacts to supported views and artifacts within the DoDAF that enable TRL and IRL assessment; and

[3] Develop a maturity assessment tool that works with standard industry SE architecture tools (e.g. Sparx Enterprise Architect).

Section 4.1 will describe the results from [1] and [2] and Section 4.2 will describe the results of [3]. The actual products of [1] and [2] can be found in Appendix A and for [3] the products can be acquired by contacting Brian Sauser at bsauser@stevens.edu or visiting http://www.SysDML.com

4.1 Mapping Readiness Levels to DoDAF

In the process of mapping maturity elements of a given readiness level to architecture artifacts, it is imperative that the selection of models can address a particular question or questions. An obstacle in this process is to choose models from the large number of standard models in DM2. To address this we followed a process that would allow us to reduce the number of choices down to a smaller subset. That is, a subset where its elements are more likely to contain the models that can address a particular question. The approach this research used to pair TRL/IRL maturity criteria to DoDAF artifacts was achieved in four steps. This is shown in Figure 2 and described below.

The first step was the extraction of all TRL and IRL decision criteria. We used the TRL Calculator and the IRL decision criteria as described by Sauser, et al. (2010) to define these criteria. An excel spreadsheet was used to populate all the decision criteria questions. When possible, composite questions with multiple parts were broken down to sub-questions to provide a more direct response. While the TRL Calculator Tool provides information on both hardware and software criteria for determining a TRL, we focused on the hardware questions only. While we believe hardware and software on most systems is inseparable, we wanted to eliminate any criteria that were ambiguous. The IRL criteria as described by Sauser, et al. (2010) do not distinguish between hardware and software.

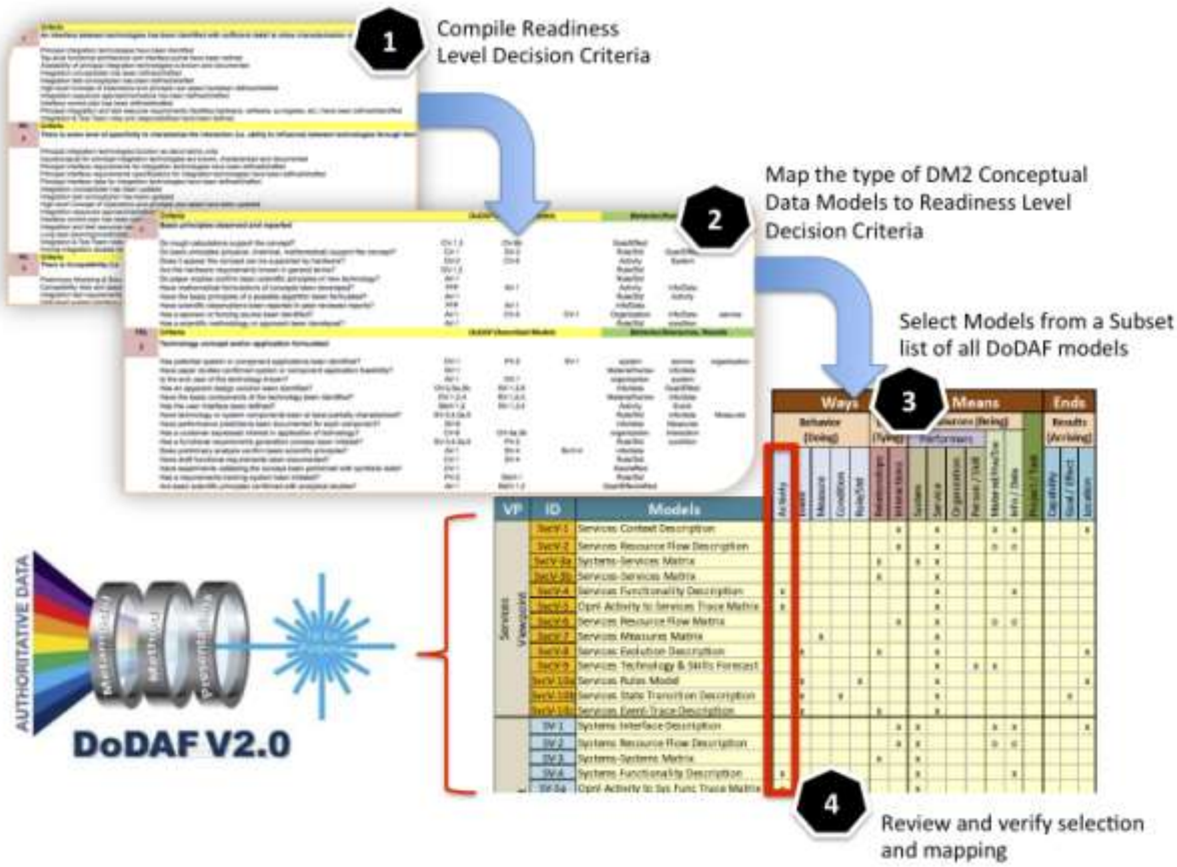

Figure 2: Artifact to Readiness Level Mapping Process

The second step was to determine the type of DM2 Conceptual Data Models (CDM) that can address each readiness level decision criteria. The CDM defines concepts involving high-level data constructs from which Architectural Descriptions are created, enabling executives and managers at all levels to understand the data basis of an Architectural Description (DoDAF 2009). The primitive underlying concept of using DM2 is to group semantically related concepts into clusters. Figure 3 below shows key concepts as they are grouped into three categories (Ways, Means, and Ends) to facilitate the identification and selection of architecture models. This helped to build Figure 3, where a matrix determines which views are addressed by any given cluster. There are some views that are more important than others, but there are times that to answer a question, the answers are distributed amongst different views.

				Description of each key concept as it relates to Maturity Assessment
Ways	Behavior	Activity		Work that transforms inputs (Resources) into outputs (Resources) or changes their state.
		Measure		The magnitude of some attribute of an individual.
		Rule	Agreement	A consent among parties regarding the terms and conditions of activities
			Standard	A formal agreement documenting accepted specifications or criteria for products, processes, procedures
	Links	Relationship		A connection, association, or involvement.
		Interaction		The interaction between two components or systems, sending data.
Means	Resources	System		A functionally, physically, and/or behaviorally related group of interacting or interdependent elements.
		Service		A mechanism to enable access to capabilities, access provided using interface. Uses Resources
		Organization		A specific real-world assemblage of people and other resources organized for an on-going purpose.
		Person/Skill		The ability, coming from one's knowledge, practice, aptitude, etc., to do something well.
		Material/HW/SW		Equipment, apparatus or supplies that are of interest, without distinction as to application
		Info/Data	Data	Information suitable for communication, interpretation, or processing by humans or machines
			Information	The state of a something of interest that is materialized -- in any medium or form -- and communicated or received.
Ends	Results	Project/Task		Planned activities that aim to change the state of some situation. A temporary endeavor to create Resources or Desired Effects
		Capability		The ability to achieve a Desired Effect under specified (performance) standards and conditions, by using ways and means
		Goal/Effect		How goals, visions, objectives, and effects relate and bear on architectures. A desired state of a Resource

Figure 3 Most popular DM2 Conceptual Data Model concepts used to facilitate the collection and usage of architecture related data

The goal of the third and fourth steps were to select models from a subset list of all DoDAF models. This was achieved by a correlation table matrix of the DM2 clusters to the list of DoDAF models (see example in Figure 4). This step helped to obtain a subset list of DoDAF described models, which may or may not address the question. A decision maker with the knowledge of DoDAF models can select the appropriate models from the subset list. Regardless, a smaller list improves the chances of the identification of models that may have otherwise been overlooked. The resulting mapping of TRL and IRL decision criteria to DoDAF models can be found in Appendix A.

Systems & Services

			Ways							Means							Ends		
			Behavior (Doing)					Links (Tying)		Resources (Being)							Results (Arriving)		
										Performers									
VP	ID	Models	Activity	Event	Measure	Condition	Rule/Std	Relationships	Interactions	System	Service	Organization	Person / Skill	Material/Hw/Sw	Info / Data	Project / Task	Capability	Goal / Effect	Location
Services Viewpoint	SvcV-1	Services Context Description							x		x			x	x				x
	SvcV-2	Services Resource Flow Description							x		x			o	o				
	SvcV-3a	Systems-Services Matrix						x		x	x								
	SvcV-3b	Services-Services Matrix						x			x								
	SvcV-4	Services Functionality Description	x								x				x				
	SvcV-5	Opnl Activity to Services Trace Matrix	x								x								
	SvcV-6	Services Resource Flow Matrix							x		x			o	o				
	SvcV-7	Services Measures Matrix			x						x								
	SvcV-8	Services Evolution Description		x				x			x								x
	SvcV-9	Services Technology & Skills Forecast									x		x	x					
	SvcV-10a	Services Rules Model		x			x				x								x
	SvcV-10b	Services State Transition Description		x		x					x							x	
	SvcV-10c	Services Event-Trace Description		x				x			x								
	SV-1	Systems Interface Description							x	x				x	x				x
	SV-2	Systems Resource Flow Description							x	x				o	o				
	SV-3	Systems-Systems Matrix						x		x									
	SV-4	Systems Functionality Description	x							x					x				
	SV-5a	Opnl Activity to Sys Func Trace Matrix	x							x									

Figure 4 DM2 clusters to the list of DoDAF models[2]

[2] J. Martin, *Architecture Frameworks & Modeling Part 2: Architecture Development*, Liberty Chapter, Mar 31 & Apr 1, 2011

4.2 SRL Tools Development

Many of the traditional tools and services are inadequate to deal with the increasing complexity of systems. As a result, systems engineers have opted for using more dedicated tools (e.g. Rational Rhapsody, Sparx Enterprise Architect) to consider all different types of information relevant to the decision making process. Thus, as our understanding of a technology changes, so should the tools we use to analyze the system these technologies and supporting integrations comprise. The goal of this phase of the research was to develop a calculator that would allow for the computation of a SRL through a standard industry systems architecture tool (e.g. Sparx Enterprise Architect). The result was a plug-in SRL calculator that would work in conjunction with Sparx Enterprise Architect (EA). In addition, because the calculator uses an export xmi file, it also has the capability with limited modifications to be used with other systems architecting tools (e.g. IBM Rhapsody).

The SRL calculator adheres to the SRL methodology and thus the SRL is a product of the TRL and IRL values. The SRL calculator extracts TRL and IRL information from a systems architecture model and reports the SRL value, the supporting Integrated Technology Readiness Level (ITRL) values, as well as a graphical aid to present the calculated values in relation to standard systems engineering lifecycle phases. To acquire a copy of the tool and supporting documentation, contact Brian Sauser at bsauser@stevens.edu or see http://www.SysDML.com.

Also as part of this a second SRL calculator was created that is not dependent on a systems architecting tool for TRL and IRL data inputs. This SRL calculator is HTML based and can be run from any web browser. A copy of the calculator can be found at http://www.SysDML.com

5 Conclusions

Architecture development efforts need to be in line with the goals and objectives of the project, hence the decision to invest in the development of a particular architecture model can depend on a variety of factors. In integrated architectures, the choice to invest in a designated model may depend on the rigor of the detail placed in alternative models which contain similar information. Hence, the selection of models differs from project to project, and is subject to the decision maker’s discretion.

As mentioned earlier, the results of this study lists the DoDAF described models that can support maturity assessment. The results of this study can introduce a new facet where maturity type information can be introduced to the system architecture. However, there is no need to make these views universal to all programs. It is not an ideal practice to interrupt the natural engineering and architecting process by focusing on specific views, regardless of their technical necessity for solving the problems at hand.

The identification of more models and maturity artifacts is advantageous to this research, as it will provide for more architectural maturity artifacts, improving technology and integration maturity assessment. However, one should be careful to notice that supplying DoDAF views of an architecture can give a false impression of "architecting" being complete (Bergey, Blanchette et al. 2009).

Throughout the development of a product, many of the ideas will need to be updated in later stages of the program. Hence, as more information about the project becomes available, this information can be updated in the system architecture model. In other words, system architecting is an iterative process.

Generally what we would expect to see in a system architecture would depend on what we would like to extract from it. To the interest of this research is information on the lifecycle, together with the decomposition into subsystems and their interrelations. For the purpose of this research, what is most important is having a repository of data and models, and being able to use them for analysis and decision making.

APPENDICES

APPENDIX A: READINESS LEVELS TO DODAF

A.1 TRL TO DODAF

TRL	Criteria	DoDAF-Described Models		
1	**Basic principles observed and reported**			
	Do rough calculations support the concept?	CV-1,3	OV-6b	
	Do basic principles (physical, chemical, mathematical) support the concept?	CV-1	SV-3	
	Does it appear the concept can be supported by hardware?	OV-2	CV-6	
	Are the hardware requirements known in general terms?	OV-1,2		
	Do paper studies confirm basic scientific principles of new technology?	AV-1		
	Have mathematical formulations of concepts been developed?	FFP	AV-1	
	Have the basic principles of a possible algorithm been formulated?	AV-1		
	Have scientific observations been reported in peer reviewed reports?	FFP	AV-1	
	Has a sponsor or funding source been identified?	AV-1	CV-5	OV-1
	Has a scientific methodology or approach been developed?	AV-1		
TRL	**Criteria**	**DoDAF-Described Models**		
2	**Technology concept and/or application formulated**			
	Has potential system or component applications been identified?	OV-1	PV-2	SV-1
	Have paper studies confirmed system or component application feasibility?	SV-1		
	Is the end user of the technology known?	AV-1	OV-1	
	Has an apparent design solution been identified?	OV-2,5a,5b	SV-1,2,6	
	Have the basic components of the technology been identified?	OV-1,2,4	SV-1,2,4,	
	Has the user interface been defined?	StdV-1,2	SV-1,2,4	
	Have technology or system components been at least partially characterized?	SV-3,4,5a,6		
	Have performance predictions been documented for each component?	SV-9		
	Has a customer expressed interest in application of technology?	CV-6	OV-5a,5b	
	Has a functional requirements generation process been initiated?	SV-3,4,5a,6	PV-2	
	Does preliminary analysis confirm basic scientific principles?	AV-1	SV-4	ScrV-4
	Have draft functional requirements been documented?	CV-1	SV-4	
	Have experiments validating the concept been performed with synthetic data?	CV-1		
	Has a requirements tracking system been initiated?	PV-2	StdV-1	
	Are basic scientific principles confirmed with analytical studies?	AV-1	StdV-1,2	
	Have results of analytical studies been reported to scientific journals, etc.?	AV-1		
	Do all individual parts of the technology work separately? (No real attempt at integration)	AV-1	StdV-1	
	Is the hardware that the software will be hosted on available?	OV-2,5a,5b		
	Are output devices available?	OV-2,5a,5b		

TRL	Criteria	DoDAF-Described Models		
3	**Analytical and experimental critical function and/or characteristic proof-of-concept**			
	Have predictions of components of technology capability been validated?	CV-2	PV-1,2	
	Have analytical studies verified performance predictions and produced algorithms?	CV-2		
	Can all science applicable to the technology be modeled or simulated?	CV-2		
	Have system performance characteristics and Measures been documented?	SV-4,7	SvcV-4,7	
	Do experiments/M&S validate performance predictions of technology capability?	SvcV-7		
	Does basic laboratory research equipment verify physical principles?	CV-2		
	Do experiments verify feasibility of application of technology?	CV-2		
	Do experiments/M&S validate performance predictions of components of technology capability?	CV-2		
	Has customer representative to work with R&D team been identified?	AV-1		
	Is customer participating in requirements generation?	CV-6	PV-1	
	Have cross-technology effects (if any) been identified?	SV-3	SV-2	
	Have design techniques been identified and/or developed?	OV-5a,5b	SV-5a,5b	
	Do paper studies indicate that technology or system components can be integrated?	FFP	CV-2	
	Has Technology Transition Agreement (TTA) including possible TRL for transition been drafted?	CV-3	SV-9	
	Are the technology/system performance metrics established?	SV-7	SvcV-7	
	Have scaling studies been started?	PV-2		
	Have technology/system performance characteristics been confirmed with representative data sets?	OV-1	PV-1	SV-1
	Do algorithms run successfully in a laboratory environment, possibly on a surrogate processor?	PV-2	SV-7	
	Have current manufacturability concepts been assessed?	CV-5	PV-2,3	
	Can key components needed for breadboard be produced?	StdV-1	SV-1	
	Has analysis of alternatives been completed?	PV-2,3		
	Has scientific feasibility of proposed technology been fully demonstrated?	OV-6a	PV-2	SV-4
	Does analysis of present technologies show that proposed technology/system fills a capability gap?	CV-1,2	SV-8	
TLR	**Criteria**	**DoDAF-Described Models**		
4	**Component and/or breadboard validation in laboratory environment**			
	Low fidelity hardware technology system integration and engineering completed in a lab environment	PV-2	SV-1 ,2,3,4,6	
	Technology demonstrates basic functionality in simplified environment	FFP	PV-1,2	
	Scaling studies have continued to next higher assembly from previous assessment	FFP	PV-1,2,3	
	BMDS mission enhancement(s) clearly defined within goals of study.	CV-2,4,6	PV-1	
	Integration studies have been started.	FFP	SV-1,2,3,4,6	
	Draft conceptual hardware and software designs.(provide copy of documentation_	OV-4,5a,5b,6a,6b		PV1,2
	Some software components are available.	CV-3	OV 2,3	
	Piece parts and components in pre-production form exist. Provide documentation.	PV-1	SV-3	
	Production and integration planning have begun. Documentation	SV-1,2,3,4,6,10a		
	Performance metrics have been established	CV-3	SV-7	SvcV-7
	Cross technology issues have been fully identified.	SV-1,2,3,4,6,10a		
	Design techniques have been defined to the point where :	OV-3,4,	PV-2	
	Begin discussions/negotiations of Technology Transition Agreement	CV-3	SV-9	

TRL	Criteria	DoDAF-Described Models		
5	**Component and/or breadboard validation in relevant environment**			
	High fidelity lab integration of hardware system completed and ready for testing in realistic simulated environment.	SV-1,2,3,4,6,10a		
	Preliminary hardware technology engineering report completed	CV-3	PV-2	
	Detailed design drawings have been completed. Three view drawings and wiring diagrams have been submitted.	CV-3	PV-2	
	Pre-production of hardware available.	CV-4,5	PV-1,2	
	Form, fit, function for application has begun to be addressed in conjunction with end user and development of staff	CV-3	PV-2	
	Cross technology effects(if any) identified and established through analysis.	SV-1,2,3,4,6,10a		
	Design techniques have been defined to the point where largest problems defined.	CV-4	PV-1,2	
	Scaling studies have continued to next higher assembly from prev assessment	SV-1,2,4,6,9,10a	PV-2	
	TTA has been updated to reflect data in items 1 thru 3, 5, 8.	CV-4,5	PV-1,2	
TRL	**Criteria**	**DoDAF-Described Models**		
6	**System/subsystem model or prototype demonstration in a relevant environment**			
	Materials, process, design, and integration methods have been employed.			
	Scaling issues that remain are identified and supporting analysis is complete.	SV-1,2,3,4,6,9,10a		
	Production demonstrations are complete. Production issues have been identified and major ones have been resolved.	PV-1,2,3	SV-9	FFP
	Some associated “Beta” version software is available.	CV-3	OV 2,3	
	Most pre-production hardware is available.	CV-3	SV-6	
	Draft production planning has been reviewed by end user and developer.	CV-5,6	PV-2	
	Draft design drawings are nearly complete.			
	Integration demonstrations have been completed, including cross technology issue Measurement and performance characteristic validations.	SV-1,2,3,4,6,9,10a		
	Have begun to establish an interface control process.	SV-2,3,8	SvcV-2,3,8	
	Collection of actual maintainability, reliability, and supportability data has been started.	CV-1,5	PV-2	SV-2,3,5a
	Representative model or prototype is successfully tested in a high- fidelity laboratory or simulated operational environment.			
	Hardware technology ”system” specification complete.	SV-4,5a	SvcV-4, 5a	
	Technology Transition Agreement has been updated to reflect data in items 1 through 4, 7 through 9, 11 and 12.	CV-4,5	PV-1,2	

TRL	Criteria	DoDAF-Described Models		
7	**System prototype demonstration in a space environment**			
	Material, processes, methods, and design techniques have been identified	SV-4	StdV-1	
	Scaling is complete.	PV-2		
	Production planning is complete.	CV-5,7		
	Pre-production hardware and software is available in limited quantities.	PV-2	SV-3	
	Draft design drawings are complete.	FFP	PV-2	
	Maintainability, reliability, and supportability data growth is above 60% of total needed data.	PV-2	SV-7	SvcV-7
	Hardware technology "system" prototype successfully tested in a field environment.	PV-2	CV-3	
TRL	***Criteria***	***DoDAF-Described Models***		
8	**Actual system completed and qualifie through test and demonstration**			
	Interface control process has been completed			
	Maintainability, reliability, and supportability data collected, and has been completed.	CV-1,5	OV-4	PV-2
	Hardware technology successfully completes developmental test and evaluation.	CV-1,5	OV-2,3,4	PV-2
	Hardware technology has been proven to work in its final form and under expected conditions.	FFP	OV-All	SV-ALL, SvcV-All
TRL	***Criteria***	***DoDAF-Described Models***		
9	**Actual system "flight proven" through successful mission operations**			
	Hardware technology successfully completes operational test and evaluation	CV-ALL	FFP	OV-All
	Training plan has been implemented.	CV-1,5	OV-4	PV-2
	Supportability plan has been implemented.	SV-1,2,3,4,6,10a		
	Program Protection plan has been implemented.	AV-2	CV-1,2,4	PV-2
	Safety/Adverse effects issues have been identified and mitigated.	SV-1,2,3,4,6,10a		
	Operation concept has been implemented successfully.	OV- ALL	PV-All	SV-All

A.2 IRL TO DODAF

IRL	Criteria	DoDAF-Described Models	
1	**An Interface between technologies has been identified with sufficient detail to allow characterization of the relationship.**		
	Principal integration technologies have been identified	SV-1	
	Top-level functional architecture and interface points have been defined	SV-1	
	Availability of principal integration technologies is known and documented	CV-3,6	PV-2
	Integration concept/plan has been defined/drafted	FFP	
	Integration test concept/plan has been defined/drafted	FFP	
	High-level Concept of Operations and principal use cases havebeen defined/drafted	CV-1	
	Integration sequence approach/schedule has been defined/drafted	FFP	SV-8,9,10
	Interface control plan has been defined/drafted	OV-2	
	Principal integration and test resource requirements (facilities,hardware, software, surrogates, etc.) have been defined/identified	FFP	SV-2,3
	Integration & Test Team roles and responsibilities have been defined	SvcV-10a	
IRL	**Criteria**	**DoDAF-Described Models**	
2	**There is some level of specificity to characterize the Interaction (i.e. ability to influence) between technologies through their interface.**		
	Principal integration technologies function as stand-alone units	SV-1	
	Inputs/outputs for principal integration technologies are known, characterized and documented	SV-2,5a	
	Principal interface requirements for integration technologies have been defined/drafted	FFP	SV-2,6
	Principal interface requirements specifications for integration technologies have been defined/drafted	SV-1	
	Principal interface risks for integration technologies have been defined/drafted	FFP	SV-1
	Integration concept/plan has been updated	FFP	
	Integration test concept/plan has been updated	FFP	
	High-level Concept of Operations and principal use cases have been updated	FFP	OV-1
	Integration sequence approach/schedule has been updated	FFP	PV-2
	Interface control plan has been updated	SV-1	
	Integration and test resource requirements (facilities, hardware,software, surrogates, etc.) have been updated	SV-2,3	
	Long lead planning/coordination of integration and test resources have been initiated	SV-6	
	Integration & Test Team roles and responsibilities have been updated	OV-2,4	
	Formal integration studies have been initiated	FFP	
IRL	**Criteria**	**DoDAF-Described Models**	
3	**There is Compatibility (i.e. common language) between technologies to orderly and efficiently integrate and interact.**		
	Preliminary Modeling & Simulation and/or analytical studies have been conducted to identify risks & assess compatibility of integration technologies	FFP	
	Compatibility risks and associated mitigation strategies for integration technologies have been defined (initial draft)	FFP	
	Integration test requirements have been defined (initial draft)	FFP	SV-1
	High-level system interface diagrams have been completed	SV-1	
	Interface requirements are defined at the concept level	FFP	SV-5a
	Inventory of external interfaces is completed	SV-3	
	Data engineering units are identified and documented	StdV-1, SV-2	
	Integration concept and other planning documents have been modified/updated based on preliminary analyses	SV-3,8	

IRL	Criteria	DoDAF-Described Models		
4	**There is sufficient detail in the Quality and Assurance of the integration between technologies.**			
	QualityAssurance plan has been completed and implemented	FFP	PV-2	
	Cross technology risks have been fully identified/characterized	SV-1		
	Modeling & Simulation has been used to simulate some interfaces between components	)V-5a/b, 6a/b		
	Formal system architecture development is beginning to mature			
	Overall system requirements for end users' application are known/baselined	AV-1	CV-1	
	Systems Integration Laboratory/Software test-bed tests using available integration technologies have been completed with favorable outcomes	SV-1,4	PV-2	
	Low fidelity technology "system" integration and engineering has been completed and tested in a lab environment	SV-1,4	PV-3	
	Concept of Operations, use cases and Integration requirements are completely defined	FFP	OV-2	SV-2
	Analysis of internal interface requirements is completed	SV-1		
	Data transport method(s) and specifications have been defined	SV-2		
	A rigorous requirements inspection process has been implemented	FFP		
IRL	Criteria	DoDAF-Described Models		
5	**There is sufficient Control between technologies necessary to establish, manage, and terminate the integration.**			
	An Interface Control Plan hasbeen implemented (i.e., Inter-face Control Document created, Interface Control Working Group formed, etc.)	FFP		
	Integration risk assessments are ongoing	FFP		
	Integration risk mitigation strategies are being implemented &risks retired	FFP		
	System interface requirements specification has been drafted	FFP	SV-1	
	External interfaces are well defined (e.g., source, data formats, structure, content, method of support, etc.)	SV-3		
	Functionality of integrated configuration items (modules/functions/assemblies) has been successfully demonstrated in a laboratory/synthetic environment	PV-3	SV-8	
	The Systems Engineering Management Plan addresses integration and the associated interfaces	FFP		
	Integration test metrics for end-to-end testing have been defined	SV-7		
	Integration technology data has been successfully modeled and simulation	SV-5a/5b		
IRL	Criteria	DoDAF-Described Models		
6	**The integrating technologies can Accept, Translate, and Structure Information for its intended application.**			
	Cross technology issue measurement and performance characteristic validations completed	SV-7		
	Software components (operating system, middleware, applications) loaded onto subassemblies	SV-2		
	Individual modules tested to verify that the module components (functions) work together	PV-2	SV-8	
	Interface control process and document have stabilized	FFP		
	Integrated system demonstrations have been successfully completed	FFP	PV-2	
	Logistics systems are in place to support Integration	FFP		
	Test environment readiness assessment completed successfully	SV-8,9		
	Data transmission tests completed successfully	FFP	SV-2,3	

IRL	Criteria	DoDAF-Described Models	
7	**The integration of technologies has been Verified and Validated with sufficient detail to be actionable.**		
	End-to-end Functionality of Systems Integration has been successfully demonstrated	SV-4	
	Each system/software interface tested individually under stressed and anomalous conditions	SV-4,8	
	Fully integrated prototype demonstrated in actual or simulated operational environment	SV-8	
	Information control data content verified in system	SV-6	
	Interface, Data, and Functional Verification	SV-1,2,3,4	PV-2
	Corrective actions planned and implemented	FFP	SV-9
IRL	***Criteria***	***DoDAF-Described Models***	
8	**Actual integration completed and Mission Qualified through test and demonstration, in the system environment.**		
	All integrated systems able to meet overall system requirements in an operational environment	CV-6	PV-3
	System interfaces qualified and functioning correctly in an operational environment	SV-1,8	PV-2,3
	Integration testing closed out with test results, anomalies, deficiencies, and corrective actions documented	FFP	SV-9
	Components are form, fit, and function compatible with operational system	SV-1,2,3,3	
	System is form, fit, and function design for intended application and operational environment	SV-1,2,3,4	PV-2
	Interface control process has been completed/closedout	SV-1,2,3	
	Final architecture diagrams have been submitted	PV-2	
	Effectiveness of corrective actions taken to closeout principal design requirements has been demonstrated	FFP	
	Data transmission errors are known, characterized and recorded	FPP	SV-3
	Data links are being effectively managed and process improvements have been initiated	FFP	SV-3,8
IRL	***Criteria***	***DoDAF-Described Models***	
9	**Integration is Mission Proven through successful mission operations.**		
	Fully integrated system has demonstrated operational effectiveness and suitability in its intended or a representative operational environment	CV-6	SV-8
	Interface failures/failure rates have been fully characterized and are consistent with user requirements	FFP	SV-1,7
	Lifecycle costs are consistent with user requirements and life-cycle cost improvement initiatives have been initiated	FFP	

APPENDIX B: REFERENCES

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